# EVOLUTION OF A CORRELATION FUNCTION OF QSOs AND THE INITIAL POWER SPECTRA OF DENSITY FLUCTUATIONS

Yu.B. Chornij, B.S. Novosyadlyj

Astronomical Observatory, L'viv State University
Kyryla and Mephodia str.8, L'viv 290005 Ukraine
*yuch@astro.franko.lviv.ua, novos@astro.franko.lviv.ua*

ABSTRACT. The evolution of two point space correlation function of QSOs ($\xi_{QQ}(r,z)$) is analyzed in the framework of the theory of the large scale structure formation. For given cosmological models the agreement between theoretical predictions and observational data on $\xi_{QQ}(r,z)$ is achieved by determination of scales of structures $R(z)$, in which could be formed quasars at different redshifts $z$. It is shown that quasars could be formed in the nucleus of massive galaxies or groups of galaxies owing to merges at their central region. It depends on an amplitude of the power spectrum of the initial matter density fluctuations at galaxy-cluster scales.

## 1. Introduction

In the problem of the large-scale structure formation the QSOs present a special interest because they cover almost all epoch of evolution of the Universe after cosmological recombination. The most physically motivated explanation of quasar phenomena is the accretion of gas and stars into the massive black holes in the center of galaxies. It would take place at the early stage of galaxy evolution or later as a result of collision or merging of galaxies in the groups or clusters. Therefore, the theoretical precalculation of spatial two-point correlation functions of QSOs ($\xi_{QQ}(r,z)$) has an important meaning for testing the cosmological scenarios of the formation of the large-scale structure of the Universe.

The analysis of quasar surveys (Iovino et al. 1991; Andreani, Cristiani 1992; Mo, Fang 1993; Komberg, Kravtsov 1995; Fang 1998; La Franca et al. 1998; Cristiani et al. 1998 and references therein) indicates on the clustering of QSOs higher than galaxies and lower than rich clusters. The observable quasar correlation function can be approximated by the expression $\xi_{QQ}(r,z) = (r/r_0^Q)^{-\gamma}(1+z)^{-\alpha}$ with $\gamma \approx 1.8$ and $r_0^Q \approx 6 - 10h^{-1}\text{Mpc}$. As it was shown by Iovino et al. 1991, Mo, Fang 1993 and Komberg, Kravtsov 1995 the amplitude of $\xi_{QQ}(r,z)$ decreases with increasing of redshift $z$ ($\alpha > 0$). But they give the different rate (values of $\alpha$) of evolution. Andreani, Cristiani 1992 did not reveal an essential evolution of $\xi_{QQ}(r,z)$.

Contrary, taking into account the last data on QSO space distribution La Franca et al. 1998 and Cristiani et al. 1998 show that amplitude of $\xi_{QQ}(r,z)$ increases with $z$. According to their results

$$\bar{\xi}_{QQ}^{obs}(15h^{-1}, z) = (r_0^Q/r)^{1.8}(1+z)^{-(1.2+\epsilon)}, \quad (1)$$

where the "fitting-parameter" $\epsilon = -2.5 \pm 1.0$. Here $\bar{\xi}_{QQ}(15h^{-1}Mpc, z)$ is integrated correlation function defined as

$$\bar{\xi}_{QQ}(r,z) = \frac{3}{r^3} \int_0^r x^2 \xi_{QQ}(x,z)dx. \quad (2)$$

The goal of this paper is theoretical interpretation of such evolution of $\bar{\xi}_{QQ}(15h^{-1}Mpc, z)$ within the framework of cosmological models with the given initial power spectra $P(k)$ and existing assumptions about physical nature of quasars.

## 2. Quasars correlation function

We assume that the QSOs are manifestation of short-term active processes, which occur in nucleuses of massive galaxies at the early stage of their evolution or later one owing the merging of galaxies in their groups or clusters (Haehnelt 1993; Haehnelt, Rees 1993; Loeb, Rasio 1994; Kontorovich 1996; Efstathiou, Rees 1998). According to the most elaborated scenario of the large scale structure formation the galaxies, their groups and clusters are formed in the peaks of the random Gaussian field of the matter density linear perturbations

owing to gravitational instability. So, the amplitude of relative density fluctuations $\delta \equiv \frac{(\delta\rho)}{\rho} = \nu \cdot \sigma(R)$ ($\nu$ is the height of peaks, $\sigma(R)$ is the root mean square of density fluctuation at corresponding scale $R$) are normally distributed. The quasar stage in an evolution of such structures begins at some moment of time $t$ (or redshift $z$), when massive black hole at center of galaxies is formed or close galaxies in most dense region of groups or clusters are merged. We can neglect an interval of time $\Delta t$, during which the quasar mechanism is formed, because it is essentially smaller than cosmological time $t$ ($\Delta t \ll t$) as it was shown by Efstathiou, Rees 1988, Haehnelt 1993, Haehnelt, Rees 1993, Loeb, Rasio 1994 and Kontorovich 1996. It means that the moment of beginning of quasar stage is close to the moment of appearence of the singularity in the Tolman solution for the collapse of dust-like cloud. In the initial random field of the density fluctuations the peaks of corresponding scale and amplitude result into such collapsing clouds. The values of $\delta$ for fluctuations which collaps at redshift z is equal to $\delta(z) = \delta_c \cdot (z + 1)$. In a case of spherical - symmetric fluctuations - $\delta_c = 1.69$, nonspherical - $\delta_c = 1.33$ (Efstathiou, Rees 1988, Nusser, Silk 1993).

In the framework of the theory of the random Gaussian fields (Bardeen et al. 1986) the two-point correlation function of peaks in which the QSOs will be formed is following:

$$\xi_{QQ}(r, z) = \left( \sqrt{\xi_{QQ}^s(r, z)} + \sqrt{\xi_{\delta\delta}(r, z)} \right)^2, \quad (3)$$

where $r$ - distance between them in comoving coordinates, $\xi_{QQ}^s(r, z)$ is the statistical component of correlation function of peaks in which the QSOs on given $z$ are formed, $\xi_{\delta\delta}(r, z)$ is the correlation function of matter density fluctuations, it is the dynamical component.

For model with given initial power spectrum of density fluctuations $P(k)$ the correlation function $\xi_{\delta\delta}(r, z)$ is equal

$$\xi_{\delta\delta}(r, z) = \frac{1}{2\pi^2} \cdot \int\limits_0^\infty k^2 \cdot \frac{P(k, R)}{(1 + z)^2} \cdot \frac{sin(kr)}{kr} \, dk, \quad (4)$$

where $P(k, R) = P(k) \cdot W^2(kR)$, $W(kR) = exp\left(-\frac{1}{2} \cdot k^2 \cdot R^2\right)$ is the Gaussian window function for the scale $R$, which corresponds to scale of fluctuations. The height of peaks of density fluctuations, in which the QSOs will be formed on fixed $z$, is defined as:

$$\nu(z) = \frac{\delta_c \cdot (1 + z)}{\sigma(R)} . \quad (5)$$

Then $\xi_{\delta\delta}(r, z)$ can be presented as follows:

$$\xi_{\delta\delta}(r, z) = \left( \frac{\delta_c}{\nu(z)} \right)^2 \cdot x(r), \quad (6)$$

where $x(r) = \xi_{\delta\delta}(r)/\xi_{\delta\delta}(0)$, $\xi_{\delta\delta}(r) \equiv \xi_{\delta\delta}(r, z = 0)$.

The expression for $\xi_{QQ}^s(r, z)$ was obtained by Novosyadlyj, Chornij 1998 by the method like Kaiser 1984 one for correlation function of rich clusters but taking into account that QSO phenomenon is short-term stage after collapse (or merging) in center of corresponding proto-object. It has the following view:

$$\xi_{QQ}^s(r, z) = \frac{1}{\sqrt{1 - x^2(r)}} \cdot exp\left( \frac{\nu^2(z) \cdot x(r)}{1 + x(r)} \right) - 1. \quad (7)$$

Substituting expression (6),(7) in expression (3), we have complete expression for correlation function of quasars $\xi_{QQ}(r, z)$ which we analyze here.

## 3. Evolution of correlation function of quasars

At the beginning let's consider the case when the QSOs are formed in structures of the same fixed scale $R$, which does not depend on cosmological time $t$. For this we will analyze the derivative of $\xi_{QQ}(r, z)$ with respect to redshift z, $\frac{\partial \xi_{QQ}(r,z)}{\partial z}$, at any fixed $r$, and find conditions which define its sign. So long as the matter density correlation function in the range where $0 < x(r) \leq \sigma^2(R)$ (that corresponds for most models $r < 30 - 40h^{-1}\mathrm{Mpc}$) is monotonous function of $r$ its derivative with respect to redshift z does not depend on value of $r$. Therefore without losing of generality we can analyze this derivative analytically in the range $x(r) \ll 1$ where the expression (7) becomes simpler:

$$\xi_{QQ}^s(r, z) = \nu^2(z) \cdot x(r). \quad (8)$$

The QSO correlation function (3) in approach $x(r) \ll 1$ will look as follows:

$$\xi_{QQ}(r, z) = \left( \nu(z) + \frac{\delta_c}{\nu(z)} \right)^2 \cdot x(r). \quad (9)$$

It means that $\frac{\partial \xi_{QQ}(r,z)}{\partial z} = 0$ when

$$\nu(z_*) = \sqrt{\delta_c}. \quad (10)$$

Taking into account (5) we shall obtain:

$$\sigma(R) = \sqrt{\delta_c} \cdot (z_* + 1). \quad (11)$$

It means, that in the case when QSOs are formed in the peaks of the same scale $R$ at different $z$ their correlation function $\xi_{QQ}(r, z)$ monotonously increases $\left( \frac{\partial \xi_{QQ}(r,z)}{\partial z} > 0 \right)$ if $\nu(z) > \sqrt{\delta_c}$ and decreases $\left( \frac{\partial \xi_{QQ}(r,z)}{\partial z} < 0 \right)$ if $\nu(z) < \sqrt{\delta_c}$. The interesting case is when condition (10) occurs at $z_* > 0$. In this case the amplitude of $\xi_{QQ}(r, z)$ decreases in the range $0 < z < z_*$, reaches its minimum at $z = z_*$ and increases at $z > z_*$.
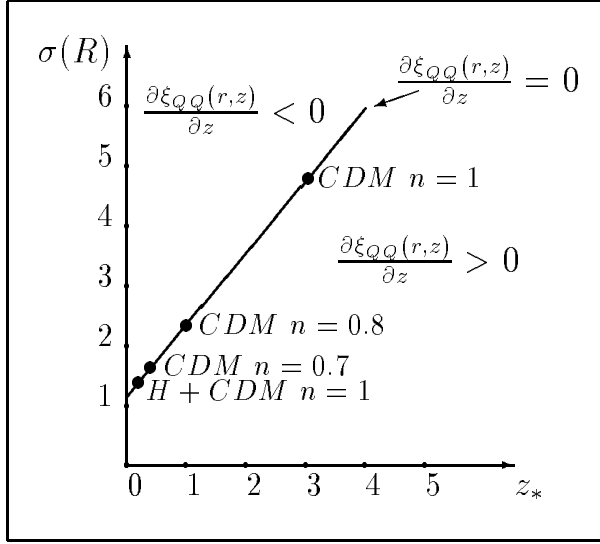
Figure 1: Izoline of minima of amplitudes of QSO correlation function $\xi_{QQ}(r, z)$ in the plane $\sigma(R) - z$. By filled circles it is shown the moments at which the evolution of QSO correlation function changes the sign for for standard CDM model, tilted ones and standard H+CDM (30%Hot+60%CDM+10%baryon) for the case when quasars are formed in the peaks of galaxy scale $R \sim 0.35 h^{-1}$ Mpc.

In particular, in the case when the amplitude of $\xi_{QQ}(r, z)$ decreases with increasing of $z$, or in the case of absence of essential evolution, that was indicated by Iovino et al. 1991, Andreani, Cristiani 1992, Mo, Fang 1993, Komberg, Kravtsov 1995, it may mean that QSOs are formed in low peaks of a random Gaussian field of matter density fluctuations, $\nu(z) \leq \sqrt{\delta_c}$. All these cases are shown in Fig.1. The solid line divides the plane into the ranges with decreasing (left) and increasing (right) the amplitude of QSOs when $z$ increases. The moments at which the evolution changes the sign for standard CDM model, tilted ones and standard H+CDM (30%Hot+60%CDM+10%baryon) one are shown by filled circles.

The values of $z_*$ for CDM models with slopes of their power spectra $n = 1, 0.8, 0.7$ are 3.16, 1.06, 0.45 accordingly. For H+CDM model $z_* = 0.21$. Thus, in the interval $0 < z < 3.16$ the amplitude of $\xi_{QQ}(r, z)$ monotonously decreases only in CDM model with $n = 1$ that agree with the data by Iovino et al. 1991; Andreani, Cristiani 1992; Mo, Fang 1993; Komberg, Kravtsov 1995. However, as it is shown by Novosyadlyj, Chornij 1998 owing to small height of peaks the amplitude of the correlation function of quasars $\xi_{QQ}(r, z)$ in this case becomes less than galactic one already at $z \sim 1$, that does not match mentioned above observational data. It may mean that quasar phenomena would be connected with structures of larger scale than galaxy one.

Therefore, let's analyze the case when scale of objects in which QSOs appear is different at different redshifts and determine them using the last data on the evolution of QSOs correlation function $\bar{\xi}_{QQ}(r, z)$ given by La Franca et al. 1998 and Cristiani et al. 1998. It can be realised in the following way: a) we set some values for cosmological parameters that give us possibility to calculate the power spectrum of density perturbations using the analytical approximation of H+CDM power spectra in four dimensional parameter space (Novosyadlyj et al. 1999), b) we determine the $R(z)$ using the $\bar{\xi}_{QQ}^{obs}(15 h^{-1} \text{Mpc}, z)$ given by (1) as input observable data at different $z$. Thereby we can determine the typical scales of structures $R(z)$, in which the quasars at different $z$ were formed. The scale $R(z)$ can specify conditions and mechanism of formation of QSOs: when $R \sim 0.5 - 1 h^{-1}$ Mpc it suggests that main part of QSOs appeared in the nuclei of massive galaxies which are not dynamically connected with structures of larger scales, when $R \geq 1 \div 2 h^{-1}$ Mpc the formation of quasars in groups of galaxies due to processes of merges of galaxies is more probable.

The calculations were carried out for redshifts in the range $0.5 \leq z \leq 3.5$ and matter dominated flat Universe with following values of the cosmological parameters: $\Omega_m = 1$ (matter density in units of critical one), content of baryons $\Omega_b = 0.096$ followed from nucleosynthesis constraint (Tytler et al. 1996), content of the neutrino hot dark matter $\Omega_\nu = 0.1$ (one sort of massive neutrino), content of the cold dark matter $\Omega_{CDM} = \Omega_m - \Omega_b - \Omega_\nu$, dimensionless Hubble constant $h \equiv H_0/100(km/sec/Mpc) = 0.5$, and different slopes of the primordial power spectrum - $n = 0.8, 1, 1.2$. The initial power spectra normalized to 4-year COBE data (Bennet et al. 1996, Bunn & White 1997) are shown in Fig. 2. For each fixed value of redshift z we calculated the integrated correlation function of QSOs (2) using the formulas (3, 4, 7), equated it to corresponding observational one (1) for $r = 15 h^{-1}$Mpc and solved the obtained equation relative to $R(z)$. The results for three models are shown in Fig. 3.

As one can see, in the models with low amplitude of the power spectrum at small scales ($n = 0.8$) the QSOs are formed in the peaks of galaxy scale $R = 0.5 \div 1$Mpc ($M \sim 10^{11} M_\odot$). And contrary, if the amplitude of the power spectrum is higher at small scales ($n = 1 - 1.2$) then the preferable range of scale of structures in which QSOs appeared are $R = 2 \div 3$Mpc, that corresponds to galaxy groups and clusters ($M \sim 10^{12} \div 10^{13} M_\odot$). It can be caused by merging of galaxies in their most dense regions at the center. We do not discuss here the drastic decreasing of such scales at small redshifts for the model with $n = 1.2$ because the analysis presented here has rather the qualitative character than quantitative. For the more certain quantitative predictions of scales of structures connected with QSOs phenomena the more realistic physical models of their formation
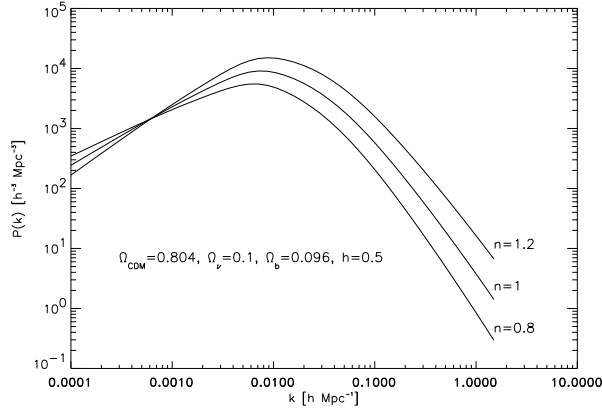
Figure 2: Power spectra of density fluctuations $P(k)$ at $z = 0$ (4-year COBE normalization) for cosmological models with parameters $\Omega_m = 1$, $\Omega_b = 0.096$, $\Omega_\nu = 0.1$, $\Omega_{CDM} = 0.804$, $h = 0.5$, and different slopes of primordial power spectrum $n = 0.8, 1, 1.2$.
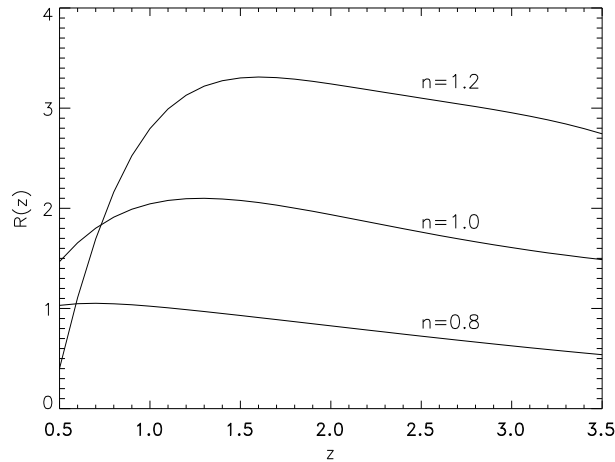


Figure 3: The scales of structures $R(z)$, in which were formed quasars at different $z$, for cosmological models with the same parameters as in a fig.2.

must be taken into account.

## 4. Conclusions

Based on the results presented here we conclude:

- The growth of the amplitude of the two-point space correlation function of QSOs ($\xi_{QQ}(r, z)$) with increasing of $z$, which was revealed by La Franca et al. 1998; Cristiani et al. 1998 can be explained within the framework of the theory of formation of the large-scale structure of the Universe from the peaks of the random Gaussian field of matter density fluctuations. The matter of explanation is that growth of statistical component of $\xi_{QQ}(r, z)$ should be faster than the reduction

of dynamical one. It can be provided by choosing of corresponding scale of structures $R(z)$ in which the QSOs were formed at different $z$ .

- The QSOs can be formed as in nuclei of single massive galaxies as in consequence of merging of galaxies in their groups or clusters. Which mechanism is statistically dominant it depends on an amplitude of the initial power spectrum at small scale.

## References

Andreani P., Cristiani S.: 1992, *Ap. J.*, **398**, L.13.
Bardeen J.M., Bond J.R., Kaiser N., Szalay A.S.: 1986, *Ap. J.*, **304**, 15.
Bennett, C.L., Banday, A.J., Gorski, K.M., Hinshaw, G., Jackson, P., Keegstra, P., Kogut, A., Smoot, G.F., Wilkinson, D.T., Wright, E.L.: 1996, *ApJL*, **464**, L1.
Bunn, E.F., & White, M.: 1997, *ApJ*, **480**, 6.
Cristiani S., La Franca F., Andreani P.: *astro-ph/9802291.*
Efstathiou G., Rees M.: 1988, *MNRAS*, **230**, 5.
Fang Li-Zhi: 1998, *astro-ph/9804106.*
Haehnelt M.: 1993, *MNRAS*, **265**, 727.
Haehnelt M., Rees M.J.: 1993, *MNRAS*, **263**, 168.
Iovino A., Shaver P., Cristiani S.: 1991, *in The Spase Distribution of Quasars, ed. D. Crampton (ASP Conf.Ser.)*, **21**, 202.
Kaiser N.: 1984, *Ap. J.*, **284**, L.9.
Kontorovich V.M.: 1996, *Astr. Astrophys. Trans.*, **10**, 315.
Komberg B.V., Kravtsov A.V.: 1995, *Astr. Astrophys. Trans.*, **8**, 241.
La Franca F., Andreani P., Cristiani S.: *astro-ph/9802281.*
Loeb A., Rasio F.A.: 1994, *Ap. J.*, **432**, 52.
Mo H.J., Fang L.Z.: 1993, *Ap. J.*, **410**, 493.
Novosyadlyj B., Chornij Yu.: 1998, *JPS*, **2**, 433.
Novosyadlyj B., Chornij Yu.: 1998, *KFNT*, **14**, 156.
Novosyadlyj B.: 1994, *KFNT*, **10**, 13.
Novosyadlyj B.S.: 1996, *Astr.Astrophys.Trans.*, **10**, 85.
Novosyadlyj B.S., Durrer R. and Lukash V.N.: 1999, A&A, 347, 799.
Nusser A., Silk J.: 1993, *Ap. J.*, **411**, L1.
Tytler D., Fan X.M., & Burles S. 1996, Nature, 381, 207.